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REGIONAL ASPECTS OF FORESTS IN EUROPE: A PRELIMINARY STUDY OF PINUS SYLVESTRIS

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ABSTRACT

As part of the first stage of the E.S.F. programme some regional aspects of Pinus sylvestris in Europe are discussed, including distribution, productivity, biomass allocation and decomposition. Multivariate analyses of available biomass data show that growth of P. sylvestris is indirectly related to latitude, but the gradient is modified by the "oceanity of the site". Further analyses of climatic data suggest that climatic classification is a useful approach to defining differences in forest growth around Europe.

INTRODUCTION

The forest of Europe are extremely heterogeneous, and within Europe's boundaries are countries which are among both the major world exporters and importers of timber products. Timber is one of the few natural resources in which Europe can expect to remain self-sufficient (FAO 1976), despite the fact that it is second only to Asia as the geographical region with least forest area and growing stock per capita (Barney 1982). Europe has about 135 million hectares of commercially exploitable closed forest, with a further 9 million hectares classified as being inaccessible or set aside for other uses. There is little doubt that forest management in Europe will intensify in coming years, with the consequence that few natural forests will remain. Examples of anticipated land use change are the conversion of scrub and open woodland in southern Europe, particularly Spain, to productive closed forest, and planting to replace natural regeneration in Nordic countries. It is predicted that, in the remainder of Europe, afforestation and reforestation will continue at the current rate of 150,000 hectares per year (Barney 1982).

Because of these changes in the forests of Europe it becomes important to consider regional aspects of forest dynamics, both in terms of rationalisation of the location of forest types and also in understanding the longer term implications of afforestation of certain areas.

We are also faced with a wider variety of questions which can only be answered by a fuller understanding of the interactions between environment and forest growth. For example, it is still not possible to predict the effects of an increased acid deposition load on natural and artificial European forests (Last *et al.* 1980), and we are still unable to accurately forecast the effects of clear-felling on run-off water quality and subsequent nutrient process within the forest (Vitousek *et al.* 1979). However it is not only the European forests that are changing but also our understanding of the ways in which forest ecosystems function, particularly the interaction between production and decomposition processes. The European Science Foundation (E.S.F.) has recognised the need for a forum where recent advances in forest ecosystem theory can be developed and applied to forestry problems. Examples of such recent research advances are: development of our understanding of ionic cycling in forests (Ulrich 1981); increased understanding of nutrient cycling in forest stands (Miller 1981); formulation of mechanistic models describing forest soil nutrient transformation (Bosatta *et al.* 1980).

Much of the experimental work leading to an increased understanding of processes occurring in forests has been carried out at a small number of sites and it is necessary to determine the applicability of the conclusions to other sites and circumstances. This is one of the long-term objectives of the E.S.F. programme and of the current work, with an initial phase of analysis of existing information followed by an expanded collaborative programme of practical research. The present paper presents the first part of an analysis of regional variations in forest dynamics, initiated in January 1983.

Recent reviews of the relation of aspects of forest dynamics to region are to be found in Reichle (1982), for a variety of natural forest types throughout the world. Fig. 1 summarises some of these relationships, and provides a framework for considering regional aspects of the dynamics of *P. sylvestris* throughout Europe. We have restricted our discussions to this species because of its ubiquity, and because it is the most extensively studied forest species.

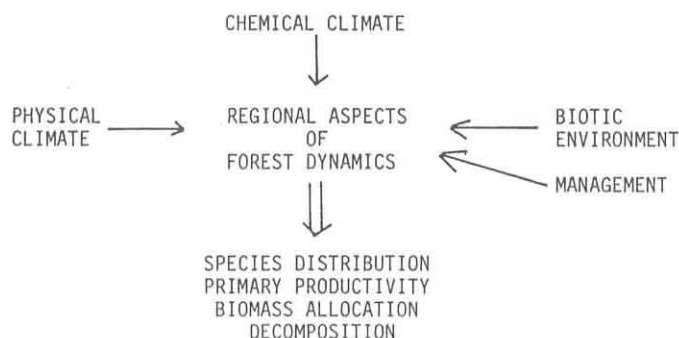


Figure 1. Regional aspects of forest dynamics, outlining the aspects discussed in the text.

We consider regional dynamics under the headings of species distribution, primary productivity, biomass allocation and decomposition as outlined in Fig. 1. The aim is to explore approaches which can be adopted and applied to other species. We also present here the first results of a climatic survey of Europe, which has the final objective of increasing the applicability of single site studies across the broader European framework.

SPECIES DISTRIBUTION

The range of natural distribution of each tree species is determined primarily by climate and, within Europe, there is sufficient range of climates for marked regional differences in tree species distribution to occur. The general trends in natural distribution of *P. sylvestris* in Europe are to be found in Jalas and Suominen (1973).

P. sylvestris is the most widely distributed conifer in the world and has a natural range including large areas of Europe. The northern limit of this range is at a latitude of around 70° N on the coast of Norway, with a southern limit of 37° N in the Sierra Nevada of Spain. The longitudinal range is believed to extend from the north-west of Spain to around 138° E (Stevens and Carlisle 1959; Mirov 1967). However, the distribution within these extremes is far from even, with large areas of Italy, Portugal, France and western Europe being excluded. The distribution as a whole suggests that it is a tree of continental climate, and the distribution in Scandinavia is an example of this; in the wet and comparatively mild climate of Norway, spruce tends to predominate over pine, whereas in Finland with its more continental climate the reverse is true.

In addition to the physical climate the chemical climate can affect the distribution of tree species. For example, a change in management strategy as a consequence of high levels of air pollution has led to the limited planting of *P. sylvestris* in the industrial areas of north-west England (Farrar *et al.* 1977). Similarly, Ulrich (1980) has suggested that acid rain and associated pollutants are causing soil changes which result in the widespread death and dieback of several tree species in certain areas of Europe, yet our knowledge of the effects of different and changing chemical climates on forest dynamics is still in its infancy.

Distribution within the natural range is determined by edaphic, topographic, biotic and management factors and, as with all tree species, must subsequently dictate productivity, nutrient inputs, nutrient cycling, decomposition processes and biomass allocation.

PRIMARY PRODUCTIVITY

Many attempts have been made to model forest productivity over large geographical areas and Paterson (1956) produced one of the first attempts to model the potential above-ground forest productivity of the world. The results of his model are redrawn for Europe in Fig. 2. He developed an index based upon environmental parameters, including: the temperature of the warmest month, annual temperature range, length of growing season, evaporation and insolation. He then related this index to potential productivity, resulting in

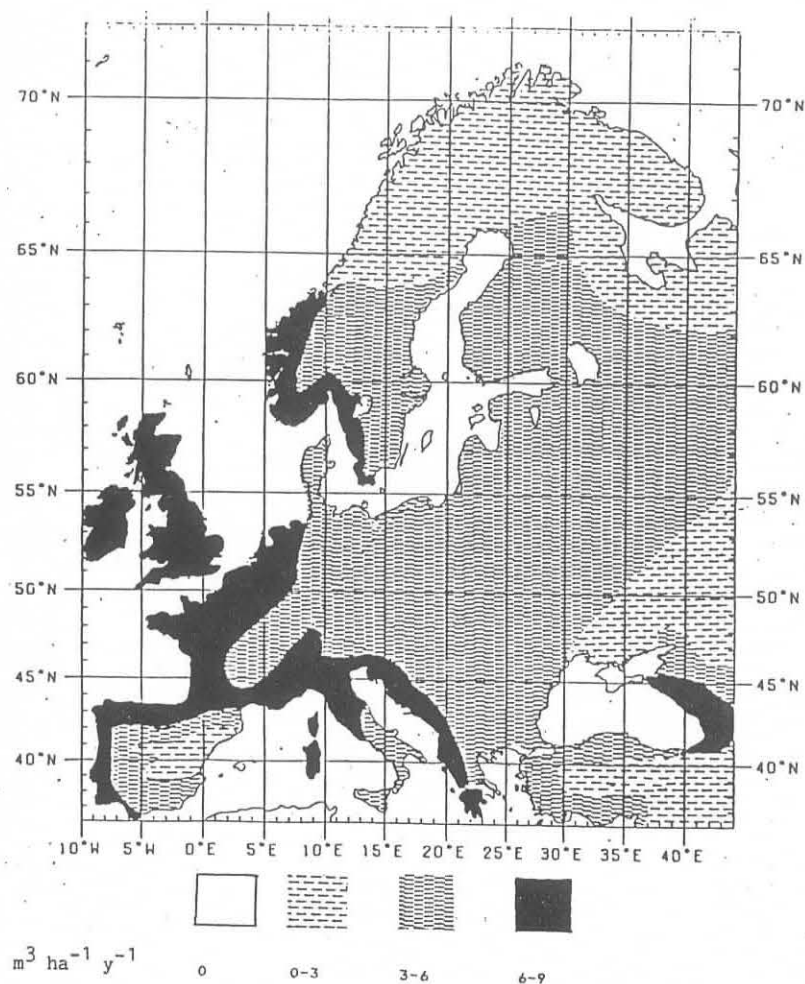


Figure 2. The forest productivity model of Paterson (1956) redrawn for Europe, showing potential timber production based upon climatic variables.

a model which described several global regions of contrasting productivity, ranging from non-productive desert and arctic zones to highly productive equatorial areas. Similar, but increasingly sophisticated models of primary productivity have been produced by other workers (e.g. Czarnowski 1964, Esser et al. 1982). The interaction between productivity and climate varies markedly between forest tree species, and large scale productivity models such as these are inevitably in error, since they ignore the interactions of individual species with environment. As an illustration of these interactions we reproduce in Fig. 3 the figures derived by Nicholls (1981) for two forest species grown in the U.K. The data presented are derived from Forestry Commission productivity figures and show timber yield in England and Wales. For *Pinus sylvestris* there is a marked regional distribution of productivity, with highest yields in the north-east and lower yields occurring to the west. In contrast, *Picea sitchensis* produces higher yields in the south and south-western region and there is an obvious interaction between species, location and yield. A more detailed analysis of the relationship between *Pinus sylvestris* and climate in the U.K. is to be found in White (1982), who suggested that variations in growth are associated primarily with solar radiation, soil texture and soil moisture content. He concluded that a reasonable estimate of height growth could be calculated if solar radiation and distance from the sea are known.



Figure 3. Regional productivity of Scots pine and Sitka spruce in the United Kingdom, from Nicholls (1981). The data was derived from individual conservancies and shows yield classes.

As a first approach to comparing the productivity of commercial forests throughout Europe, Christie and Lines (1979) compared yield tables for various species which are grown throughout Europe. We have expressed the available yield table data for *P. sylvestris* in the form of a map (Fig. 4). Unfortunately, it is both at a coarse national resolution and incomplete, yet it does provide some indication of the comparative annual increments of *P. sylvestris* across Europe. *P. sylvestris* was chosen for this map because of its wide natural range and because it has been the subject of many yield studies. The map shows the mid-point of the range of mean annual increments for the individual countries as extracted from Christie and Lines (1979). There is a wide range of mean annual increment across Europe, from 18.4 cu m/ha in Hungary to less than 3 in northern Scandinavia. Similarly, the range of climates is broad, from northern Lapland with a mean temperature in the growing season (defined as the period with temperature > 5 C) of 10 - 10.5 C to Turkey where the equivalent mean is 10 C higher.

Comparison of Fig. 2 and Fig. 4 shows that the map of Paterson fails to reflect the within region variation in productivity of *P. sylvestris* and emphasises that productivity is dependent upon the species grown, as is shown by the data presented in Fig. 3. For example, Christie and Lines (1979) suggest that the change in yield of *P. sylvestris* across Europe is less marked for *Picea sitchensis* indicating that accumulated temperature is less important for *Picea sitchensis*, where a longer growing season and a high site moisture content are critical. Productivity would therefore appear to be dominated by species/climate interactions at the European level, yet more detailed data, comparable to those of Nicholls (1981), are necessary to define further these interactions. The collation of existing forest productivity data from within each country of Europe is one of the first stages in the current programme of work, to define the reasons of production to climate and to relate production to nutrient cycling processes.

BIOMASS ALLOCATION

There are few studies of the allocation of photosynthate to different fractions of biomass in *P. sylvestris* with respect to region, and those that have been performed have concentrated on aspects such as cone size, seed weight and needle length (see Pravdin, 1969). A general trend appears from such studies suggesting that, as one travels from the northern limits of the species southwards, seed weight, cone weight and percentage seed viability all increase (Pravdin, 1969). Analysis of the woodlands data set from the International Biological Programme suggests that there is an inverse linear relationship between litterfall, both total and leaf, and latitude (O'Neill and DeAngelis 1981), and this trend may well apply to *P. sylvestris*. The same general conclusion was reached by Bray and Gorham (1964) in their review of litter fall from a wide range of woody and herbaceous species. Examination of *P. sylvestris* data presented by Cannell (1982) shows that age dominates the partitioning of biomass to wood and foliage, with older stands having a greater relative amount of wood. As the stand ages the amount of wood increases (see below) and, since the amount of foliage is far less age-dependent, the ratio of wood/foliage increases. Jordan (1971) suggested that the efficiency of wood production increases as solar energy input decreases, yet this is still insufficient to prevent wood production from

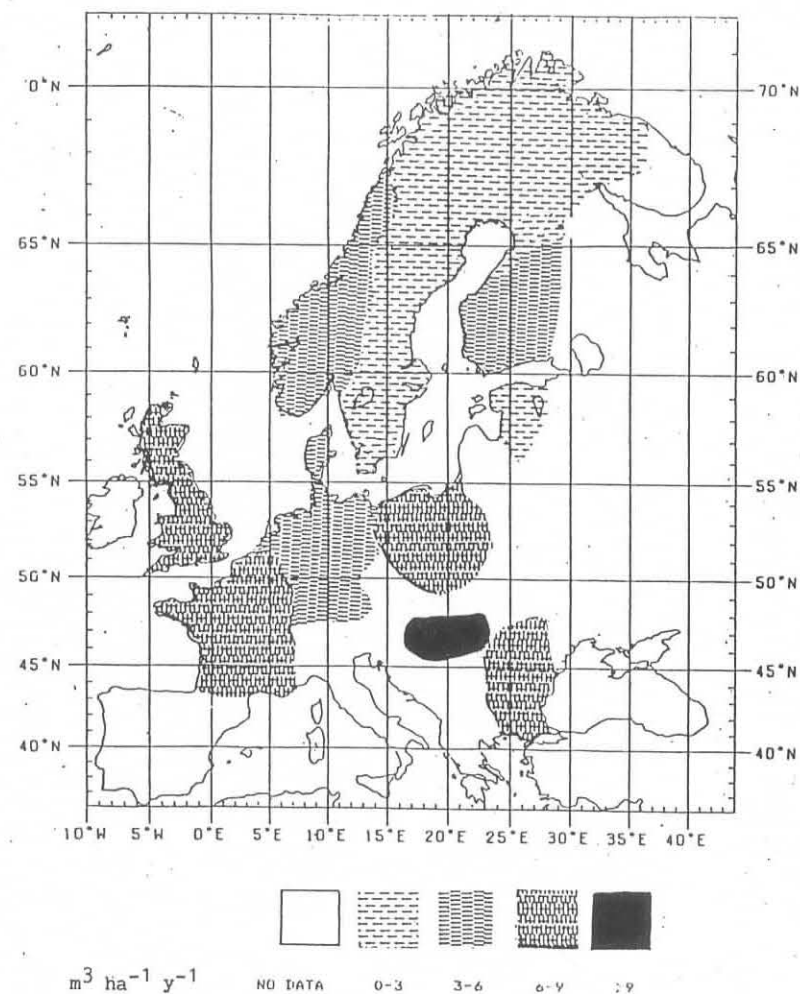


Figure 4. Regional productivity ($\text{m}^3 \text{ha}^{-1} \text{y}^{-1}$) of *Pinus sylvestris* in Europe as indicated by yield tables. Data was extracted from Christie and Lines (1979) and shows the mid-value of the range of mean annual increment for individual countries.

decreasing in the northern latitudes (O'Neill and DeAngelis 1981). These authors also show that the proportion of wood products in total litter fall decreases with increasing above-ground net primary production. Thus, the allocation of biomass in *P. sylvestris* is dependent upon climate, yet the data available within Europe are extremely limited, and largely ignore allocation to below ground biomass.

It is suggested that in its more southerly ranges *P. sylvestris* allocates a greater proportion of photosynthate to non-wood tissue, having more frequent needle fall, larger needles and heavier seeds and cones. This will effect nutrient distribution, enhancing subsequent nutrient release during decomposition.

DECOMPOSITION

Miller (1981) suggests that pine forests maintain highly conservative nutrient cycles, and that provision of nutrient by the litter and soil organic matter is important in maintaining productivity particularly in mature stands. In those boreal forests where nutrient limitation is occurring, the process of decomposition, and its control by the physico-chemical environment, are of major importance in determining stand productivity. The recent model of Ågren (this volume) for nitrogen limited boreal forests indicates that mineralisation of nitrogen from soil organic matter is a critical process in determining site productivity, and that more information about the climatic control of nutrient release during decomposition is required.

Swift *et al.* (1979) defined the three major factors which determine the decomposition rate of litters in terrestrial systems as substrate quality, physical environment and organisms. Of primary importance is the quality of the substrate (Q) which is not only a characteristic of a given plant species but also a product of the species and environment. Within a species the decomposition of branch and bole wood is considerably slower than for foliage (Gosz *et al.* 1973) and the allocation of biomass to woody or foliage tissue is of importance in determining subsequent decomposition processes. Furthermore, the release of nutrients from such substrates is very different, with a tree stump acting as a potential nitrogen sink for up to 20 years (Heal *et al.* 1982), whereas needle litter may mineralise nitrogen after only a year or so on the ground (Staaf and Berg 1982). In the majority of tree species the proportion of foliage litter to woody litter is high, with leaf litter accounting for 70 % of litterfall on a world-wide scale (Meentemeyer *et al.* 1982). This appears to be of a comparable order to that found for *P. sylvestris*, and the data of Mälikönen (1974) give an average of around 82 % for a group of mature stands in Finland. This percentage appeared to decrease slightly with increasing stand age. Thus, the above-ground input to the decomposer sub-system in pine is predominantly as needles and it is this fraction which has been studied most extensively. Mikola (1955) studied the decomposition of leaf litters from a variety of tree species, including *P. sylvestris*, and showed that percentage weight loss differed between species, with *Picea abies* litter decomposing less readily than Scots pine litter, and deciduous litters decomposing more rapidly. It is believed to be the low

base-status combined with the presence of waxes, resins and lignins which makes leaf litter of *P. sylvestris* so resistant to decomposition (see Millar 1974). In fact, Kendrick (1959) suggested that typical pine needles took at least 9 years to decompose at a forest site in the U.K., which is supported by observations at other sites (see Millar 1974).

The loss in dry weight during needle decomposition has been measured by several workers under a variety of conditions for Scots pine, yet a regional comparison of such studies is limited because of differences in initial Q, which are known to effect the first stages of decay (Berg *et al.* 1982a). Mikola (1960) was perhaps the first person to investigate the decomposition of pine litter in a regional context when he compared decomposition rates in northern and southern Finland. He found that the rate of weight loss of Scots pine needles increased as mean summer temperatures increased. In southern Finland (60 20'N) the average rate was about 40 % faster than at a latitude of 68 02'N. Both Q and physico-chemical climate varied in this experiment, yet the author suggested that the effects of temperature on decomposition were of major importance. Although we have some detailed information on the basic processes and rates of decomposition and nutrient release in pine litter in Sweden (Berg *et al.* 1982a, 1982b; Staaf and Berg 1982) there are few data available concerning the effect of climate upon these processes (Berg and Jansson, this volume). The work of Bunell *et al.* (1977) and Meentemeyer (1978) supports the suggestion that temperature and moisture are critical variables influencing the rate of litter disappearance, and it is physico-chemical climate which Swift *et al.* (1979) describe as the second factor controlling decomposition (P). Bunnell *et al.* (1977) adopted a simplistic approach to modelling oxygen uptake by decomposing litters, assuming a Q_{10} relationship between activity and temperature, whilst using a Michaelis-Menten saturation relationship for modelling the effect of moisture content. The fit between predicted and measured respiration rates was sufficiently good to conclude that these two abiotic variables are of primary importance in dictating decomposition rates for a particular type of plant litter. Similarly, the close correlation between annual actual evapotranspiration and weight loss of specific forest litters shown by Meentemeyer (1978) supports this conclusion.

The variety of major ecosystem types occurring across Europe means that the rate and nature of decomposition can be expected to differ markedly within Europe. In general, as one proceeds south from the pole to the Equator the climate becomes more favourable for decomposition processes, in terms of temperature and moisture and in the length of the season when decomposition can occur. Net primary production also increases along this cline, yet soil organic matter shows a reverse trend. The relationships between climate and net primary productivity and decomposition differ, resulting in a climatic controlled accumulation of soil organic matter with, for example, cold climates tending to encourage a build-up of soil organic matter (Swift *et al.* 1979). Esser *et al.* (1982) have attempted to model these balances between production and decomposition in their litter pool model, and the results of this model have been redrawn for Europe in Fig. 5. These data were derived by applying two basic models, firstly the Hamburg model for primary productivity and, secondly, a litter depletion model for rate of litter decay. Both models used temperature and rainfall as key independent variables, with the Hamburg model incorporating soil type to modify estimated productivity. The depletion model, in particular, should be viewed with caution since many assumptions

have been made in its construction, yet it does provide useful indications as to where one can expect productivity to exceed decomposition, and litter accumulation to occur. The model suggests that accumulation of soil organic matter is not simply related to longitude, and that the extreme northern range of Europe does not favour the accumulation of organic matter as suggested above. This is at variance with the trends described in Rosswall and Heal (1975), and suggests that a revision of the underlying equations in the model is required.

The third major factor defined by Swift et al. (1979) was that of the organisms (O), and as one moves from the boreal zone to the warmer Mediterranean zone, general changes in the soil flora and fauna may be expected. The taiga is characterised by sub-zero winter temperatures, with the majority of decomposition taking place in a limited summer season, being performed by reduced macrofaunal populations and low fungal biomass. The quality of the litter (Q) tends to be poor, with a lower water-soluble component, and a high level of modifiers of an inhibitory or recalcitrant nature. This contrasts markedly with the more southern temperate areas of Europe, where the soil is rarely frozen, and both temperature and moisture favour decomposition. The season over which decomposition can occur is extended and there is a greater biomass and activity of soil animals. *P. sylvestris* is characteristically a mor forming tree species and shows a limited rate of decomposition at most sites, with the process being dominated by fungi and cryptostigmatid mites. The limited data comparing successions on Scots pine litter at different sites suggests that inter-site differences in fungal successions may be significant (Mitchell et al. 1978) although the reasons for, and the implications of, these differences are not clear.

CLIMATIC CLASSIFICATION

We have extracted biomass data from Cannell (1982) for 18 pure stands of *P. sylvestris* in Europe, and used multiple regression techniques to identify those factors which correlated with biomass accumulation and allocation in these stands. Appropriate meteorological data were obtained from Met. Office (1982), and included monthly temperature maxima and minima, mean monthly precipitation, monthly bright sunshine data and humidity. The data were extracted from the nearest meteorological stations at comparable altitudes to the stands, with no correction for elevation being made. Additional variables derived from Cannell (1982) and maps, included: distance from Atlantic, distance from sea, latitude, longitude, stand density and age.

Above-ground biomass (wood + foliage) was linearly related to $\log(\text{age of the stand})$, and a combination of $\log(\text{age})$ plus distance from the Atlantic accounted for 79.7 % of the variance in above-ground biomass. The inclusion of other variables failed to increase the explanation of variance. However, the distance from the Atlantic was correlated with several climatic variables, namely hours of bright sunshine and maximum temperatures for several months of the year. Thus, it would appear that the "oceanity" of the site influences the biomass accumulation of *P. sylvestris*, and that "oceanity" is a complex variable related to the interactions of temperature and moisture.



Figure 5. Calculated litter pools of Europe, redrawn from Esser et al. (1982). The pool was derived by dividing predicted litter production by depletion rate. The map shows combined results for both woody and herbaceous litter.

In order to more clearly identify the trends in climate which occur across Europe we used a variety of multivariate analyses to create a climatic classification of sites throughout Europe. It was hoped that such an approach would help to quantify "oceanicity", and in so doing relate to the productivity of a variety of forest species.

Data were taken from contour maps of mean monthly temperature and rainfall for January, March, May, July, September and November for the whole of Europe, including Iceland, but excluding parts of eastern Finland, Poland, Rumania and Bulgaria (UNESCO, 1970). This was achieved using an overlay grid of 301 squares, each subdivided into four. The resultant 1204 points were at approximately 60 km intervals, with slight variation (+5 %) depending on latitude, due to distortion from the map projection. Mean monthly temperatures and rainfall were determined at each of the 1204 points, as was the latitude of the square to the nearest degree.

The data were subjected to different methods of multivariate analysis; first, Principal Component Analysis (PCA) on the raw data, followed by cluster analysis on the first five axes; second, Indicator Species Analysis (ISA) on attributes derived from the raw data, followed by reciprocal averaging of the component scores, and subsequent trend surface analysis. Both methods resulted in an almost identical division, the first axis in the classification being based on temperature. 46.4 % of the variation in the PCA was explained by the first eigenvalue and, in the ISA analysis, a critical attribute for the first division was a January mean temperature of $< -5.0^{\circ}\text{C}$. This resulted in a split which identified most of Scandinavia with Iceland, leaving extreme western-most parts of southern Norway, and the remainder. In Fig. 6 we present a map of Europe based upon the results of the cluster analysis. Places designated by the same symbols have similar climates with respect to rainfall and temperature. For example, isolated points in the Alps are shown to be akin to areas in Scandinavia, and these can be related to high altitudes on a topographic map.

The second PCA axis, explaining 26.3 % of total variability, was related to rainfall, whilst the third axis, accounting for a further 11.4 %, was more complicated. This third axis distinguished between wet and dry summers, in contrast to total annual rainfall, and identified areas which were alike in certain aspects of seasonality.

CONCLUSIONS

In Fig. 7 we bring together results from the biomass studies described above and the climatic classification. The graph shows, as expected, that the older a stand gets the more wood biomass it contains in boles and branches. By identifying the individual sites as they appear from the cluster analysis in Fig. 6 it can be seen that a general trend emerges. Those sites in the Arctic regions identified by the first of the ISA divisions show different accumulation of wood to those located in other regions. Unfortunately the biomass data set is limited, yet the effects seen here support the trends outlined in Fig. 4, with an increase in productivity being associated with the southern regions of Europe.

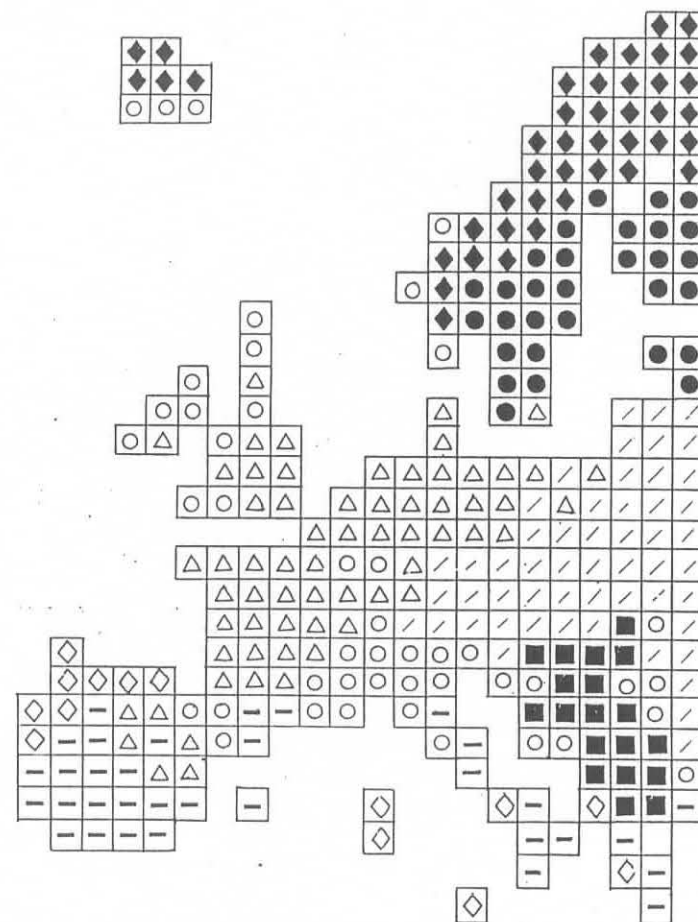


Figure 6. Climatic classification of Europe based upon cluster analysis of temperature and rainfall data. Regions of similarity are shown with the same symbol.

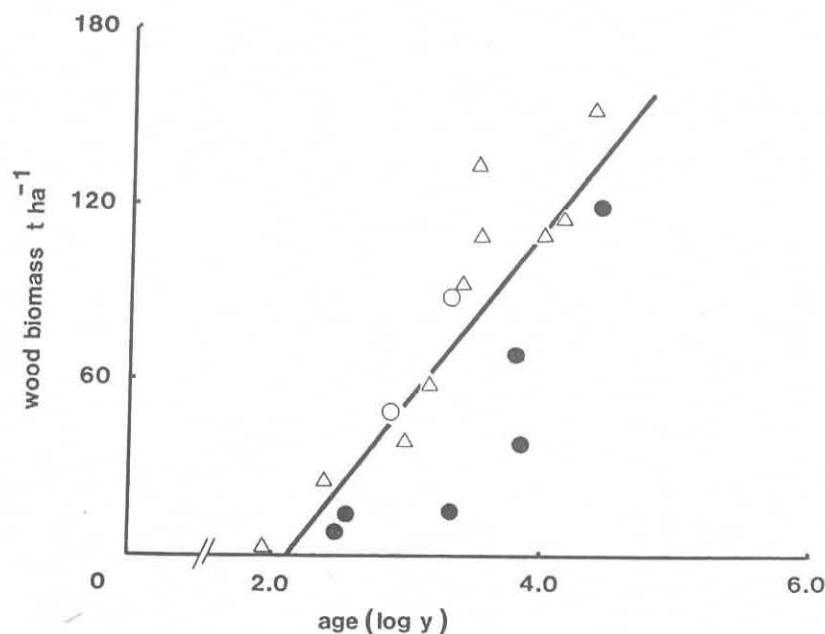


Figure 7. The accumulation of wood biomass by *Pinus sylvestris* with age, for pure stands growing in Europe. The symbols correspond to those used in Fig. 6. The line was fitted using linear regression ($n=18$, $r=0.80$).

The trend surface analysis performed on the component scores of the ISA revealed two distinct climatic trends across Europe; a latitudinal trend associated primarily with temperature and an oceanic trend linked to precipitation. The two clines suggested by Christie and Lines (1979) as being important in determining the productivity of *P. sylvestris* are borne out here, and appear to dominate individual site differences. Thus, climatic classification can provide a useful tool in identifying trends in multivariate data and has potential both in modelling forest growth and in selecting European sites for further study. However the climatic classification must be modified by soil characteristics, as in Esser et al. (1982), to improve interpretation of production and decomposition relationships.

From the discussion of the regional aspects of forest dynamics it can be seen that much information about the timber productivity of stand of a variety of tree species is available within the individual countries of Europe. The collation of such data within a European framework provides an opportunity for relating the growth of forest species to physical and chemical climates, and this is one of the objectives of the current E.S.F. project.

Unfortunately, the data concerned with allocation of productivity within stands are few, despite the increasing potential importance of whole-tree harvesting. The rate of removal of nutrients by such harvesting can only be predicted if we have adequate knowledge of biomass allocation, and how this changes with age and environment. This knowledge is also central to predicting the rate of nutrient release during decomposition. Similarly, more information on the rates of decomposition and nutrient mineralisation in different regions is of fundamental importance to our modelling of forest productivity at nutrient limited sites, and of the influence of other disturbances, such as fire, which disrupt nutrient circulation.

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